(Annex 2)

【Moonshot Goal 5】

"Creation of Food Supply Industry That Enables Sustainable Global Food Supply with No Overburden Nor Waste by Full Use of Unutilized Biological Resources by 2050" Research and Development Conception

March 2020 Ministry of Agriculture, Forestry and Fisheries

1． Moonshot Goal

Among Moonshot goals (Decision of Council for Science, Technology and Innovation, January 23rd, 2020), we promote research and development to achieve the goal shown below.

<Moonshot goal>
"Creation of food supply industry that enables sustainable global food supply with no overburden nor waste by full use of unutilized biological resources by 2050"

(Targets)
○ By 2050, fully utilize biological functions of microorganisms and insects, and others and develop a complete resources recycling food production systems.
○ By 2050, develop solution methods that eliminate food loss and waste and promote healthy and environmentally friendly reasonable food consumption.
○ By 2030, develop and demonstrate a prototype of the above systems, and promote discussion on ethical, legal and social implications (ELSI) in parallel to globally spread the systems by 2050.

(Research promotion organization: Bio-oriented Technology Research Advancement Institution)

2． Necessity of setting the Moonshot goal

To date, we have been developing farmland, forest land and oceans on the earth in line with the pace of world population growth and have realized food supply by making full use of various technologies. However, it has also brought about destruction of the natural environment and overexploitation of natural resources causing various problems such as soil deterioration due to excessive use of chemical fertilizers and pesticides, and contamination of rivers and groundwater.

In recent years, the global warming due to greenhouse gases has become more serious, and the reduction of such gases has become an urgent task. Globally, a quarter of the total emission of greenhouse gases including nitrous oxide and methane are said to be caused by the agricultural, forestry and other land use.

In 2050, the world population will reach 1.3 times (compared to 2010) , and the synergistic effect with the increase in demand for grain as livestock feed in medium income countries is expected to increase food demand by 1.7 times , so further expansion of the food supply is required. However, although organic substances, which are the source of food circulate as crops, foodstuffs, matters of emission, soil materials and so on, the circulation collapses under the current methods of food production which emphasizes only production efficiency, and this adversely effects the global environment including climate change and obstruction of food supply sustainability. To achieve both increasing food production and conserving global environment, we should revise current food production methods radically.

On the other hand, it is presumed that there should be a large number of unutilized biofunctions in microorganisms and insects. It is important to elucidate the unexploited "knowledge" and to create new socio-economic activity systems by making full use of natural and biological functions.

Therefore, in order mankind to continue to secure food sustainably in the future and to expand the amount of food supply in line with the pace of the growth of the world population, it is indispensable to develop a complete resources recycling food production systems by which the biological functions of microorganisms, insects, and others are fully utilized.

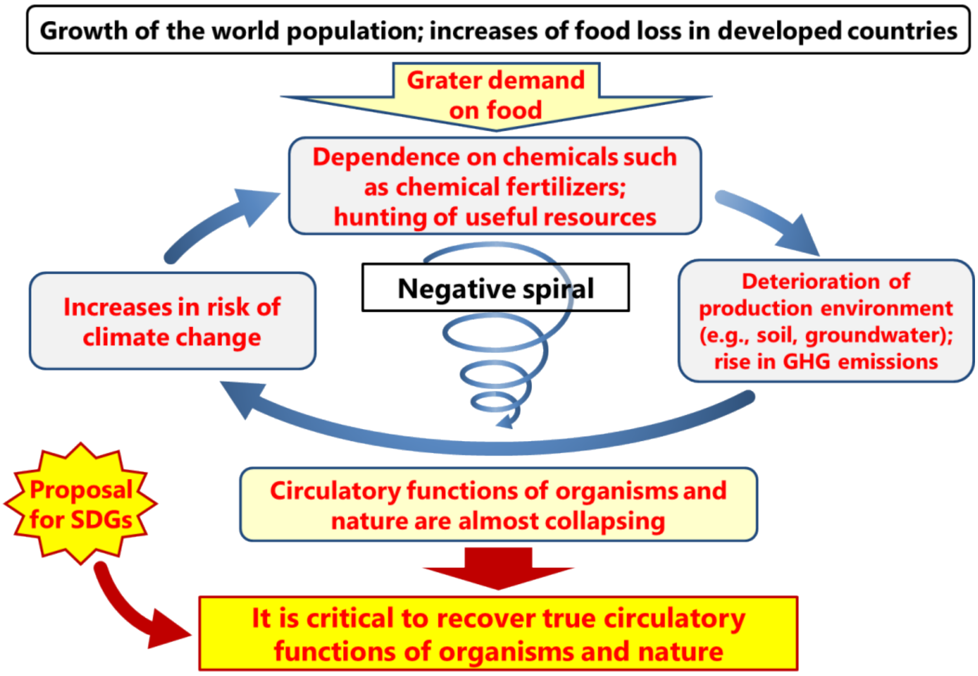

Figure 1. Challenges in food supply in view of 2050

In addition, it is necessary for us to reconsider consumer behavior in future. Currently, social problems, such as the waste of large amount of food, and increases in obesity and lifestyle-related diseases are mainly occurring in developed countries, including Japan.

Therefore, it is required to take challenging actions that will expand globally through the creation of solution methods that eliminate food loss and waste and encourage rational consumption actions considered health and environment.

Furthermore, the United Nations Sustainable Development Goals touts the importance of followings, and today international collaborative activities are starting.

(1) Promoting sustainable food production systems that strengthen capacity for maintaining ecosystems and adaptation to climate change (Goal 2)
(2) Significantly expanding afforestation on a global scale and promoting conservation of mountainous ecosystems including their biodiversity (Goal 15)
(3) Conserving oceans and ocean resources, and utilizing them in a sustainable manner (Goal 14)
(4) Reducing food waste and food losses, and ensuring sustainable patterns of production and consumption (Goal 12)

In view of the above, there is an urgent necessity to bring together the wisdom of researchers and businesspeople throughout the world to promote challenging research and development aiming to "Creation of food supply industry that enables sustainable global food supply with no overburden nor waste by full use of unutilized biological resources by 2050", to respond both the anticipated future growth of the world population and conservation of the global environment.

3. Direction of Research and Development

Based on the discussion on Moonshot International Symposium (December 17th and 18th, 2019) and so on, the direction of research and development at the moment is shown as follows.

(1) The Target Areas of Challenging Research and Development

To achieve a sustainable increase in food production while responding to climate change that is expected in the future, it is necessary to remarkably improve the environmental adaptability of crop plants. In addition, to maintain the food production, it is also required to prevent adverse effects on the global environment by drastically reducing the dependence on water and artificial materials and striving for conservation of biodiversity. Therefore, it is essential to elucidate the unused biofunctions of insects, soil microorganisms, microorganisms in human body, plants, and others, and utilize it for creating a complete resources recycling food production system.

On the other hand, as the food supply expands, it is also significant to utilize the produced food effectively and without food loss, thus it is required to make an innovation in our consumption behavior itself. While we are currently facing social problems, such as environmental deterioration by the waste of large amount of food, and the increase in obesity and lifestyle-related diseases which are mainly occurring in developed countries, the starvation problem has not yet been solved. Therefore, it is indispensable to develop new solutions which will reduce food loss and waste, and reliably deliver the necessary amount of food to the people who require it.

In view of the above, it is necessary to establish the food production and consumption systems that achieving both food supply expansion and global environment conservation by fully utilizing unused biological functions, however, at this moment it is too technically difficult to realize it, and research and development on elucidation and utilization of biofunctions is at the initial stage now and far from social implementation. Therefore, we suppose that “achieving both the expansion of food supply and the preservation of global environment” should be promoted as the field/area of challenging research and development in Moonshot Research & Development Program.

（2）Research Subjects Toward Moonshot Goal

In Moonshot Research & Development Program, we promote research and development by recruiting widely from home and abroad challenging research and development in the above target field/area that should be promoted.

In the promotion of research and development, we will target to be the technological development that contributes to the achievement of Moonshot goal and at the same time to be the challenging issues and will take a wide range of technological approaches that have been scientifically validated and conducting them with setting Stage Gate. In addition, we investigate the latest scientific trends and utilize them in research and development so that we can take the most efficient and effective means.

And from the perspective of smooth social implementation of the research results, the research system in which researchers with various backgrounds can participate about ethical, legal, and social implications (ELSI) matters shall be examined.

<Food Production Systems Achieving Both Food Supply Expansion and Global Environment Conservation>
Supposed examples of research and development are described below.

- Elucidating the whole mechanism of “resilience” of wild species that can resist poor environmental conditions
- Creating new lineage of plants with designed functions by reconstructing plant genomes from nothing
- Development of technology to make full use of soil nutrients and to reduce emission of greenhouse gases by complete control of the soil microbial environment
- Developing complete pest control technology unaffecting ecosystems
- Creating plants and algae with high ability to absorb carbon dioxide and developing circulation system of organic substance by utilizing them

<Food Consumption Systems Realizing Zero Food-loss and Waste>
Supposed examples of research and development are described below.

- Developing systems that can match and deliver all supply and demand needs for food instantly in cyberspace
- Developing super-long food conservation technology by fully utilizing biological functions
- Developing effective conversion/reuse technology for healthy and environment-conscious edible food, such as the development of 3D food printing and cocking systems that converts surplus agricultural products and household food residue into cartridges and reuses them
- Developing technology to converts food residues and forest residues into food and aquaculture feed by fully utilizing biological functions

（3）Direction of Research and Development Toward Moonshot Goal

○ 2030 (Output Goals)

<Food Production Systems Achieving Both Food Supply Expansion and Global Environment Conservation>

Develop and demonstrate the prototype of “the complete resources recycling food production systems by fully utilizing biological functions.”

<Food Consumption Systems Realizing Zero Food-loss and Waste>

Develop and demonstrate the prototype of “the solution methods for encouraging rational food consumption considered health and environment.”

○ 2050 (Outcome Goal)

“Creation of food supply industry that enables sustainable global food supply with no overburden nor waste” means that both “the complete resources recycling food production systems by which the biological functions are fully utilized” and “the solution method s for encouraging rational food consumption considered health and environment” are spread globally. The image of 2050 (outcome goal) is shown in Figure 2.

For achieving the outcome goal in 2050, regarding “the complete resource recycling food production systems by fully utilizing biological functions” and “the solution methods for encouraging rational food consumption considered health and environment”, after setting up the site for demonstration and solving the next necessary technological development issues at each stage, it is necessary to secure a period for the diffusion of products and system. In addition to that, in parallel with research and development, discussion on the ethical, legal and social implications (ELSI) matters is also necessary. Thus, the goal by 2030 is establishment of prototypic technology.

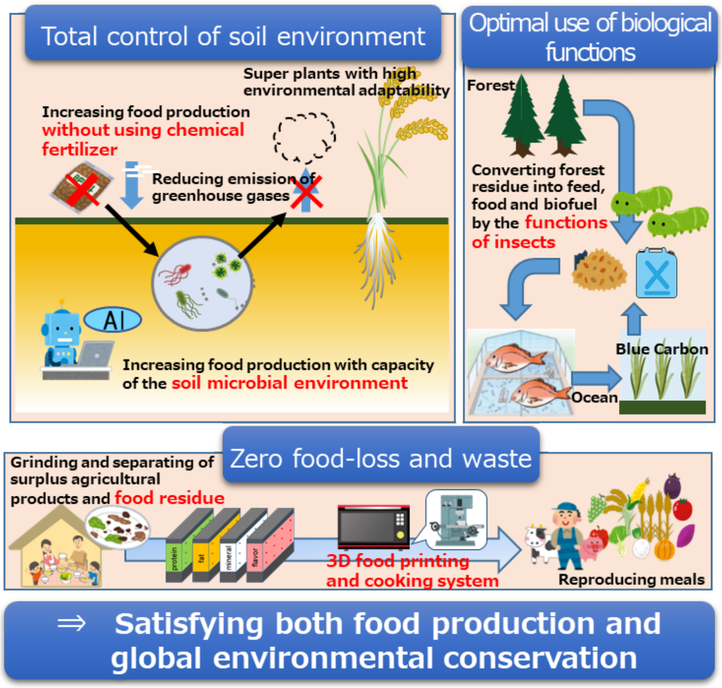

Figure 2. The image of 2050 (outcome goal)

<Reference : Analysis Toward Moonshot Goal>

Based on the Initiative Report at Moonshot International Symposium (December 17th and 18th, 2019) and so on, analysis toward Moonshot goal is shown as follows.

（1） Technology and Research Trends Related to the Food Production System Achieving Both Food Supply Expansion and Global Environment Conservation

Studies on the interaction between plants and soil microorganisms (Figure 3, gray line) and symbiosis between plants and microorganisms (green line) are continuously ongoing and have been increasing since around 2012. There has been a slight increase in research on soil microorganisms and greenhouse gases since 2015, but the number of studies is still small (yellow line). Studies on genome editing in microorganisms have been increasing since 2013 (orange line), but when limited to research on soil microorganisms, the number is extremely small (11 cases, data not shown). Therefore, studies on the design and modification of soil microorganisms could be regarded as a field of research from now on.

On the other hand, the number of studies on genome editing in plants has increased rapidly since 2013 (blue line). This coincides with the time when CRISPR/Cas9 began to be applied to plants. It seems that research results on topics including the development of basic technology for genome editing and crop creation using genome breeding technology have come out. In contrast, there are still few studies on breeding using AI (39 cases, light blue line), which shows that this research is in its infancy. However, the number of cases began to increase in 2019 and research in this field is expected to increase rapidly in the future.

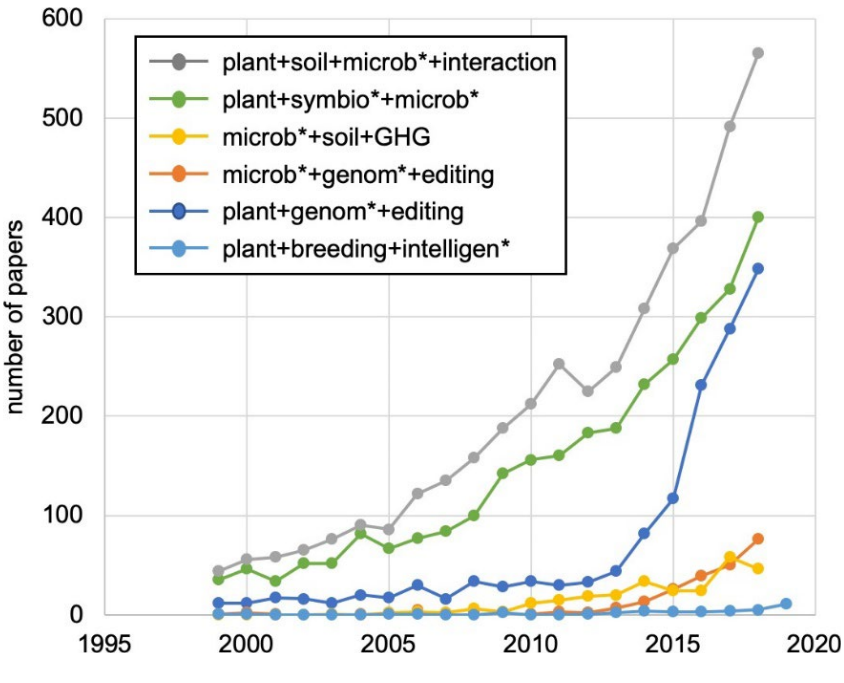

Figure 3. Research trends on breeding and soil microorganisms in Japan and overseas from 1999 to 2019 (Clarivate Analytics, Web of Science)

An overview of the research trends on the development of pest control methods, shows that the two predominant fields with the largest number of papers to date are chemical control (chemical pesticides) and biological control (use of natural enemies of pests) (Figure 4-A). The next largest fields of research are related to physical control, cultural control, resistant varieties, symbiotic microorganisms, and release of infertile insects. Of these, the two areas in which the number of research cases has increased significantly over the past five years are the use of symbiotic microorganisms and the release of infertile insects (Figure 4-B, purple and light blue line). However, the number of studies on pest control using genome editing has increased rapidly in the last three years and research using drones and AI is also starting to increase. Research in these fields is expected to increase in the future (Figure 4-C).

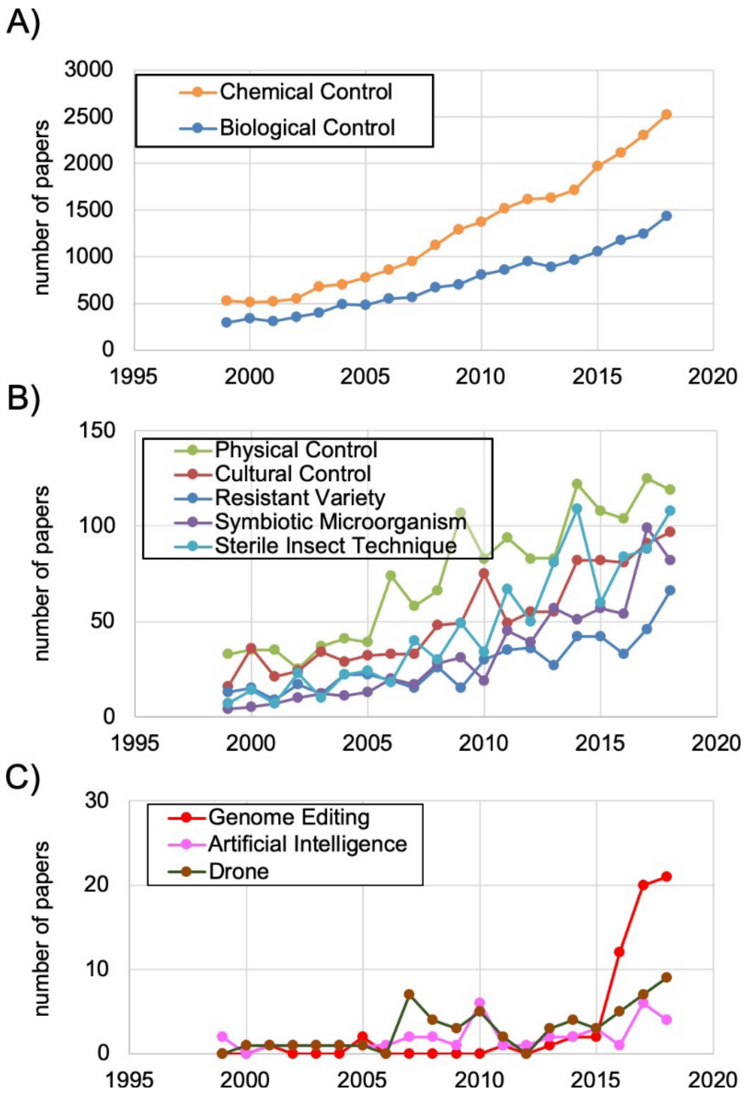

Figure 4. Research trends on pest control in Japan and overseas from 1999 to 2018 (Clarivate Analytics, Web of Science)

In the field of life sciences, omics analysis at the single cell level has become possible over the past few years, and imaging technology has made significant progress.

Furthermore, the accuracy of genome editing technology has improved, and it is being developed for medical and food applications. Information and communication technologies (ICTs) such as measurement technology and AI machine learning are steadily permeating life sciences through automation and scaling-up. In addition, understanding of life phenomena is progressing through a new “data-driven” approach to discover laws from a great number of life phenomena. On the contrary, with the progress of AI, genome editing, synthetic biology, and so on, ELSI are positioned as an important element in the promotion of science and technology (R&D overview report, integrated version 2019).

（2） Technology Trends Related to Food Consumption System for Achieving Zero Food Loss

Research into food losses and waste has been on the increase (Figure 5), particularly in the last five years. While much of the literature in around 2000 is in the fields of zoology, sociology, nutritional science, and water resources, research in the fields of transportation science technology, transportation, and telecommunications has seen growth in recent years.

This indicates growing momentum toward actively managing mismatches in transfer of food from the stages of production through consumption (i.e., in food supply chains), which are largely responsible for food losses and waste.

On the other hand, for food chain management related to food losses and waste, it is considered useful to link food supply chains to AI- based information networks, particularly IoT and ICT, which have progressed rapidly in recent years, but research in this field has made little progress, with only three studies in 2014 and eleven in 2018. The key characteristic of fresh foods is the fact that they deteriorate in quality or decay during the distribution process after harvest, and eventually become worthless. Therefore, future application of IoT to food distribution should take into consideration not only information about the quantity of food, but also about its quality (such as quality changes over time).

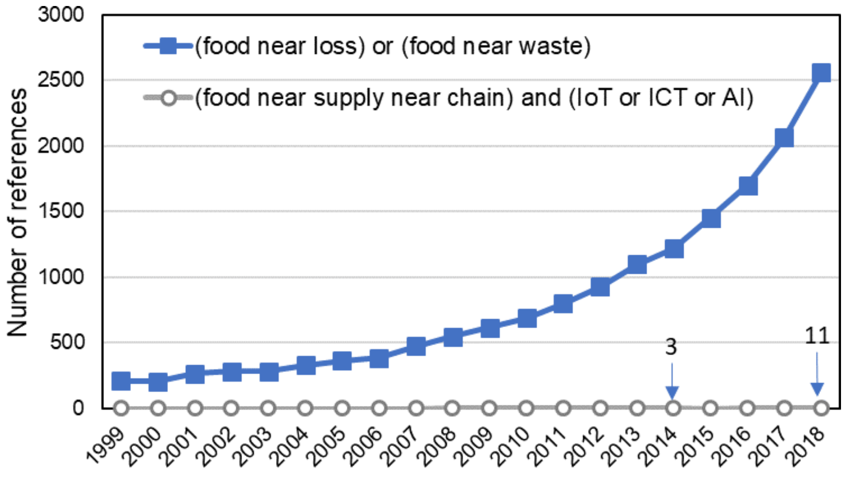

Figure 5. Research trends in food losses and waste, and food supply chains (Clarivate Analytics, Web of Science)

When considering the active use of food losses and waste, one solution is to convert them into energy or materials. Among the existing research projects on food losses and waste, studies addressing these topics account for approximately 24% and 14%, respectively, suggesting a relatively large interest (Figure 6). Methods of converting food to energy or materials include smart use of biofunctions, in addition to chemical and physical methods. Although related research has been conducted to date, however, it accounts for only about one-seventh of the research into energy and materials conversion overall.

Meanwhile, recycling of food losses and waste has been the subject of highly successful projects such as one on fermented liquid feeding (Sasaki et al., 2011), but such studies represent as little as 5% of all research projects on food losses and waste. This area of research is far from being advanced due to issues of social acceptance and technical difficulties.

In addition to supply to livestock farming (livestock feed, etc.), which has already been researched and has been established as a part of the system, another potential approach to recycling would be to take advantage of Japan's ocean resources to explore the possibility of aquaculture applications for food losses and waste; however, little attention has been paid to this area so far.

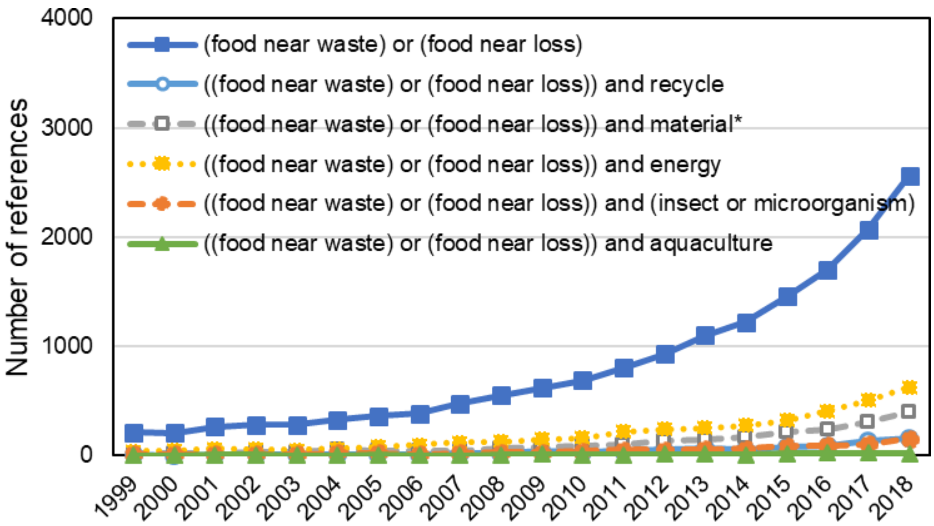

Figure 6. Research trends in food losses and waste focusing on recycling, materials/energy conversion, insects/microorganisms, and aquafarming (Clarivate Analytics, Web of Science)

One means of reducing food loss, waste, or disposal is the method of "reprocessing" into foods with excellent nutritional benefits and taste by using edible resources such as surplus agricultural products, non-standard products, and by-products as food materials. In recent years, the development of 3D printing technology has been remarkable (Figure 7). Such 3D printing technology can produce small quantities as well as many individual items and is thus considered a promising means of enabling individuals to select various foods in the food field. However actually, there are few studies on the use of 3D printers in the food field (Figure 7 orange) as opposed to the industrial field. In addition, the materials used in the food field are limited to ingredients that are easy to put into the printer.

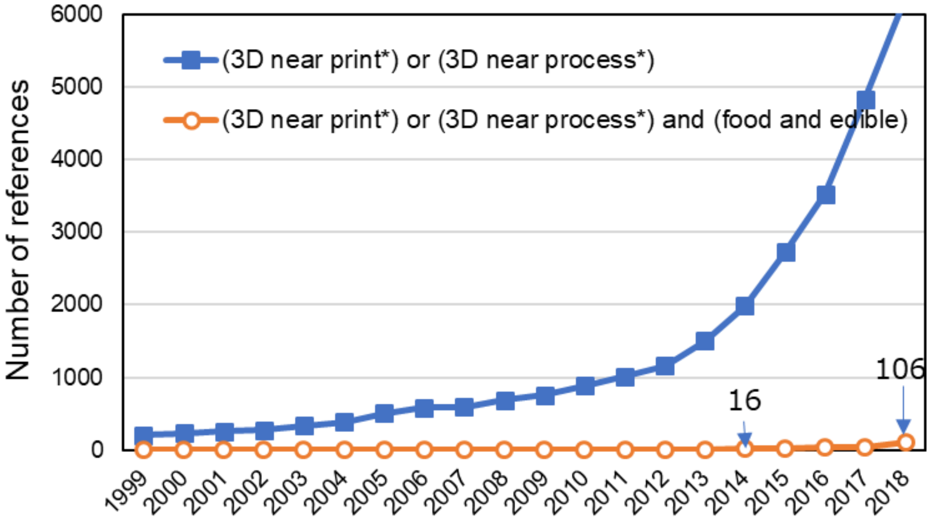

Figure 7. Research trends in food losses and waste, and food supply chains (Clarivate Analytics, Web of Science)